# The purification study on the Liquid Scintillator for JUNO

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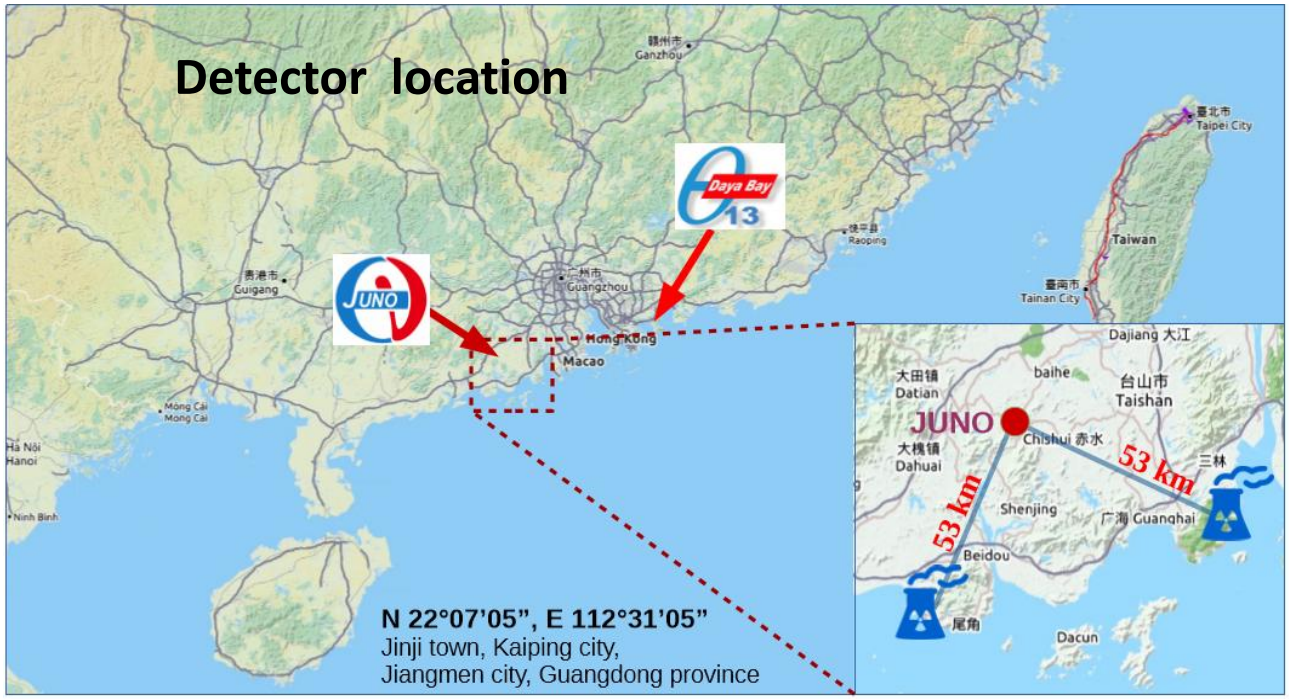
# Jiangmen Underground Neutrino Observatory



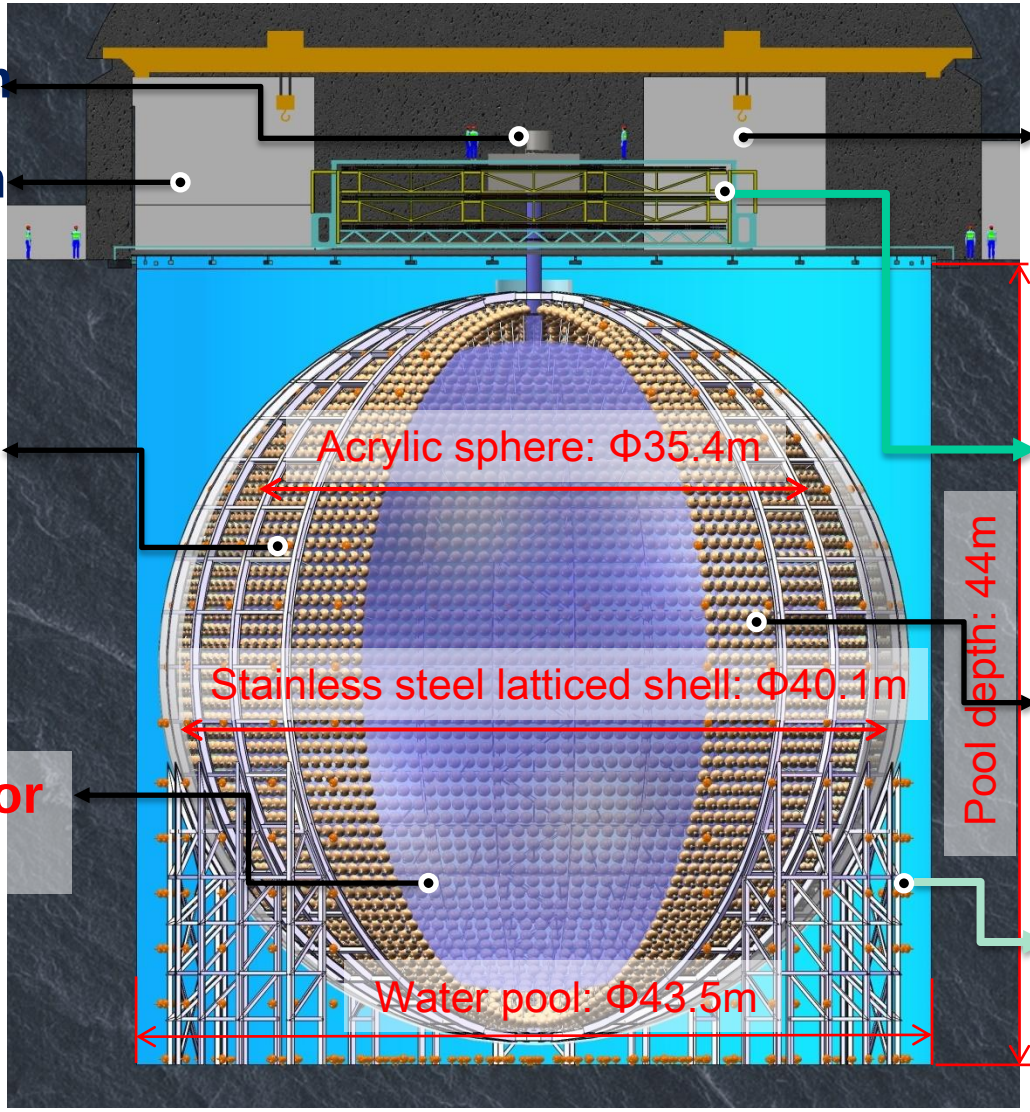

- Sources: reactor neutrinos, 6+4 cores (Yangjiang and Taishan NPP, under construction):
- Baseline : 53km
- Under 700 m deep underground for muon flux reduction.

- Primary physics goal is for the neutrino mass hierarchy determination.
- Large detector volume, good resolution and low background allow rich physics goals: supernova, geo-, solar … neutrinos
- Central Detector: 20-kton liquid scintillator with 18k 20'' PMTs + 25 k 3'' PMTs

# JUNO detector

**Calibration room**

**Pure water room**




**LS Filling room**

**Central detector**
SS latticed shell
Acrylic sphere

**Top Tracker**

**PMT**
~18,000 20” PMTs
+ ~25,000 3” PMTs:
coverage >75%

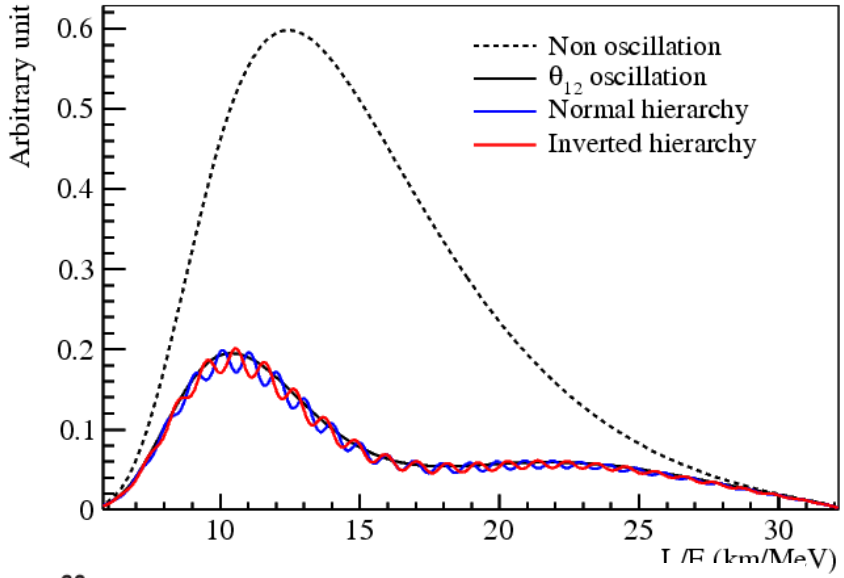
**Liquid scintillator**
20 kton

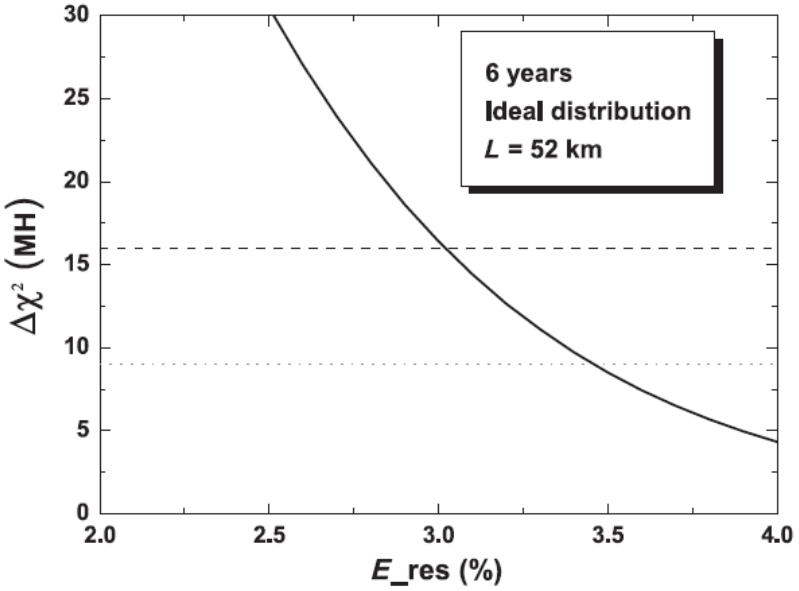
**Water Cherenkov**
35 kton pure water
2,000 20” veto PMTs

# Energy resolution

- Determination of mass hierarchy requires precision measurement of energy spectrum
- Sensitivity heavily depends on the energy resolution
- JUNO aims for 3%/√E(MeV)
  - ~1200PE@1MeV→

    2.89% statistical fluctuation
  - high light yield, high transparency and low background liquid scintillator
  - high optical coverage and high QE PMTs.



# LS Requirements

## 20 ktons LS for Central Detector

Requirements for LS:

- High light yield: ~1200 p.e./MeV
- Long attenuation length: >20m
- Low radio-impurity: $^{238}U/\ ^{232}Th<10^{-15}g/g$, $^{40}K<10^{-17}g/g$

**Preliminary recipe:**
**LAB + 3g/L PPO + 15mg/L bis-MSB**

Linear alkyl benzene (LAB)
- Commercially available
- Relatively cheap
- Transparent
- High light yield
- Biodegradable
- High flash point：130
- Chemical inertness
- Compatible with acrylic



Purity of PPO ≥99.5%
A.L. @430nm ≥ 20m
(for 3g/L PPO in LAB)

# Four purification systems studied

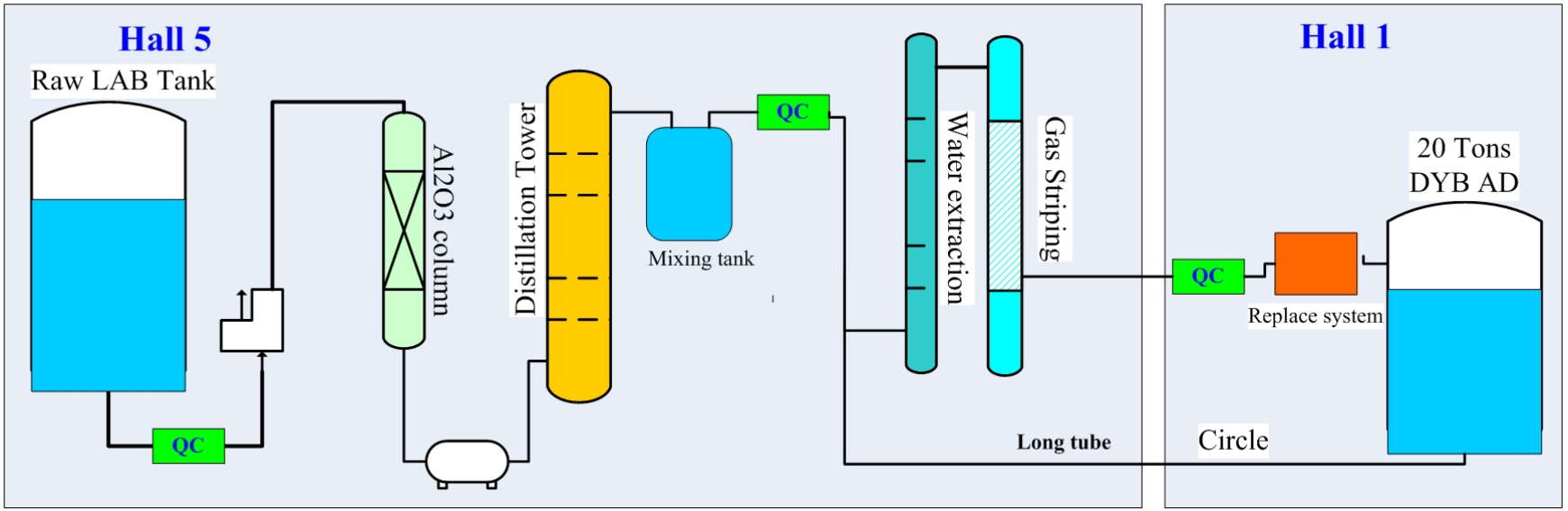
- $Al_2O_3$ column plant is based on the "absorption" technique to remove optical impurities and increase the A.L. of LAB
- Distillation plant is to remove heavy metal, improve transparency
- Water extraction is to remove $^{238}U$, $^{232}Th$ and $^{40}K$ .
- Gas Stripping plant remove the impurities : Ar, Kr and Rn.

Optical and radioactive purification

# LS purification prototype test

- To meet the requirement of LS for JUNO, the purifications of LS Raw materials LAB, PPO et al. are focused. After large number of purification research in the laboratory, a purification pilot plant has been established by INFN and IHEP in Dayabay LS hall.
- The test will study:
  - effects of light emitting substance
  - concentration to light yield and energy nonlinearity
  - check radioactive background
  - Which purification method will be used and how to combine them ?
  - Pre-study for JUNO LS mass production;

# Pilot plant of JUNO LS at DYB LS Hall




- All four purification systems will be tested ($Al_2O_3$ column, distillation, water extraction and N2/steam stripping);
- Flow rate is 100～150 l/h;
- Every system will be checked respectively , then the purified LS by whole system will be filled and checked by one DYB AD detector;

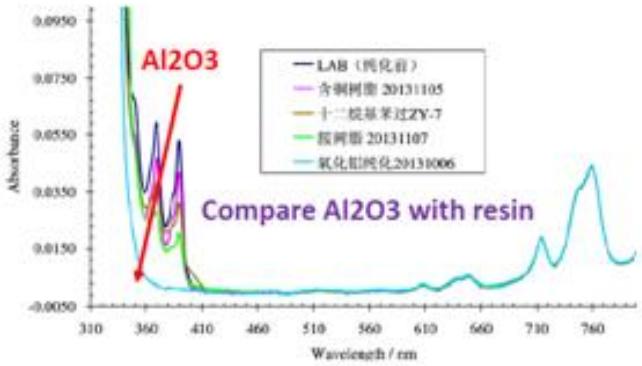
# $Al_2O_3$ column plant

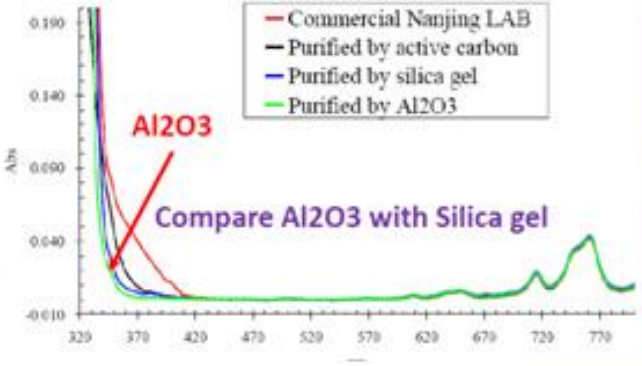
## Improve the optical performance of alkyl benzene

Bench-top experiments to get basic parameters for pilot plant

Packing materials: Al2O3, silica gel, charcoal, resin…

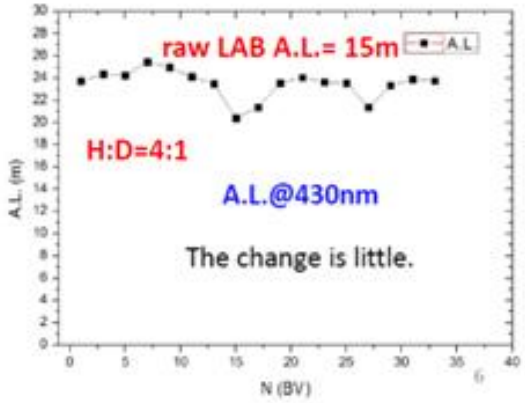
**Al2O3 is the best one to Improve the optical for LAB**





### H:D experiment result




### Al2O3 column test in Lab.


Al2O3 column system has been built in Dayabay LS Hall

Main parameters:

Column H:D=5:1;

Flux rate: > 100L-150L/h;

Column Diameter:500mm;

Column Height:3000mm

Total height: 4.5m

# Distillation plant

Small scale Distillation tests have been done on several LAB samples from different producers: the distilled samples had showed better optical characteristics (both absorption and emission) than the original not purified ones. No deterioration of the LAB was noticed.

**Distillation pilot plant installed in DYB LS hall**

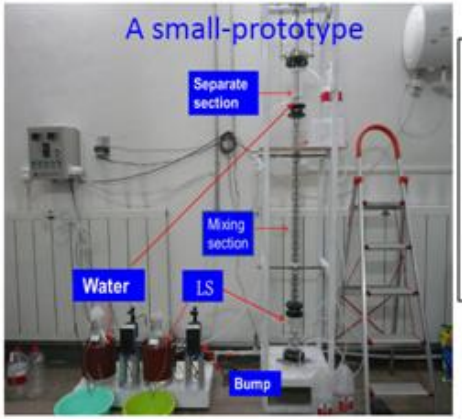
**Distillation pilot plant main parameter:**

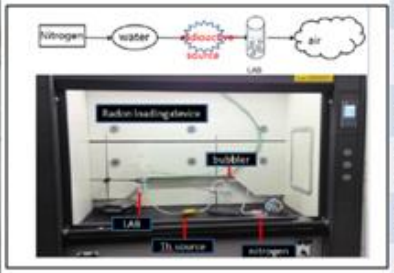
- Flow rate 100 l/h
- Distillation under vacuum with sieve trays
- without downcomers
- 6 physical trays
- 1-2% adjustable bottom column discharge
- High reflux rate (nominal 25%)
- Heat exchanger energy recovery

# Water Extraction plant

A small-prototype of W.E. Plant
Flux Rate: 1~2L/h Diameter: 40mm
_loading the LS with suitable radioisotopes
Purification efficiency:
80% at R.T., 90% at 40-80 ◦C

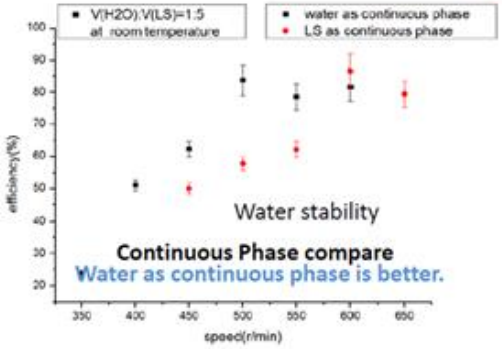
Optimization of parameters for pilot plant
- Optimization of rotation speed, flow and flow ratio
- Choose water as continuous phase
– higher purify efficiency, lower speed and more stable

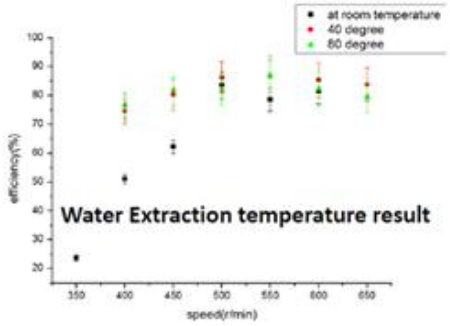



| item | Parameter |
|---|---|
| Flux Rate | 170 L/h |
| Diameter of column | 150mm |
| Height of Column | 3.5m |
| Speed | 0~200r/min |
| Paddle Stages | 27 |
| Theory Stages | >5 |
| Temperature | RT~80$^0$C |


loading the LS with suitable radioisotopes




The water extraction pilot plant installed in Daya Bay LS hall.

# Gas Stripping plant

Stripping plant will be based on the “steam stripping” technique to remove the impurities that are more volatile than LAB: Ar, Kr and Rn.

High temperature (100°C ) for higher column efficiency

- Partial vacuum (around 300 mbar)
- Both steam and nitrogen stripping could be tested in the plant
- All the plant is kept under continues nitrogen blanket either to avoid oxidation/contamination but also for safety reason
  (LAB temperature < flash point)
- Vapor condenser before water vapor/nitrogen exhaust for safety
- Rupture disks for pressure safety

**Gas Stripping pilot plant installed in DYB LS hall**

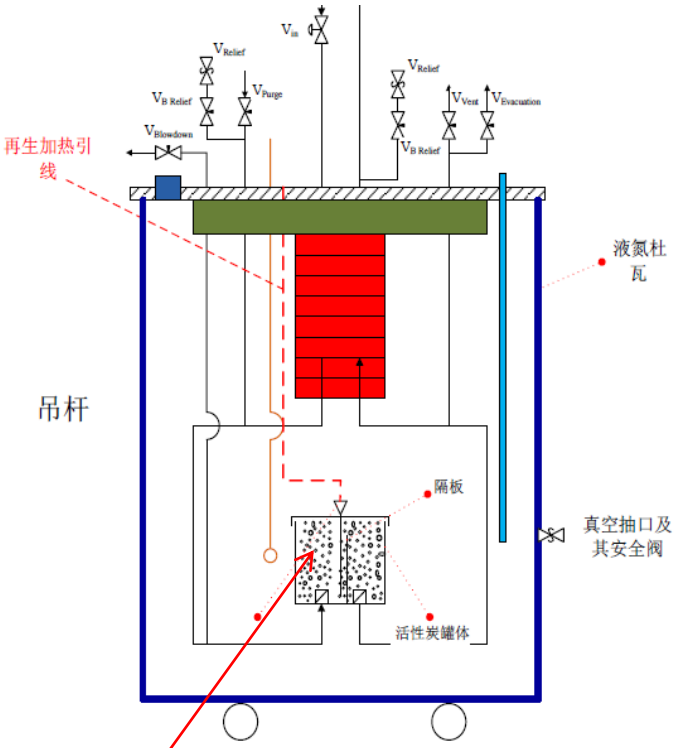
# General plants requirement

- All stainless steel parts (AISI 316L) will be electro polished
- Orbital welding
- Precision cleaning will be done before assembly
  - Washing with detergent
  - Pickling, passivation and chelating agents (EDTA)
  - Water rinsing by de-ionized water (DI) of all surfaces to reduce deposits
  - Final Nitrogen purging
- Vacuum leak tightness for total system leak rate < $10^{-6}$ mbar l /s (10-8 mbar l /s each)

# High purity Nitrogen system

- The high purity nitrogen pilot plant developed; it will supply the high pure nitrogen for **nitrogen blanket** of LS purification plants;
- **It can be used as stripping gas (Nitrogen Stripping);**

| Operating Temperature | 77K |
|---|---|
| Operating pressure | 0.6MPa |
| Nitrogen flow rate | 50Nm$^3$/h |
| Nitrogen purity at outlet | Ar & $O_2$:<30ppm |
| Radon level at outlet | Better than 5uBq/m$^3$ |
| Leak rate | <5.0*10$^{-8}$Pam$^3$/s |



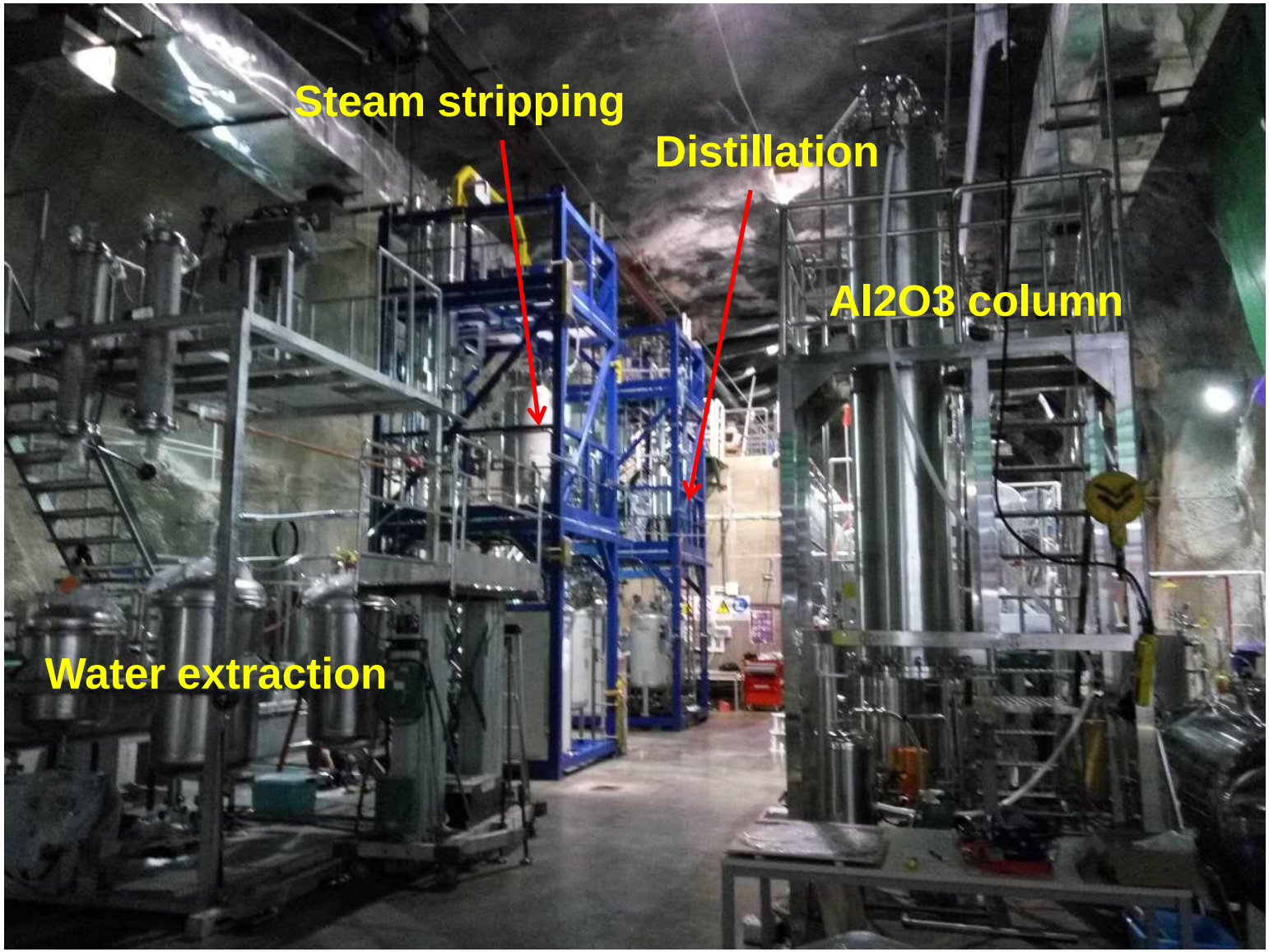

Design Drawing

LTA technology

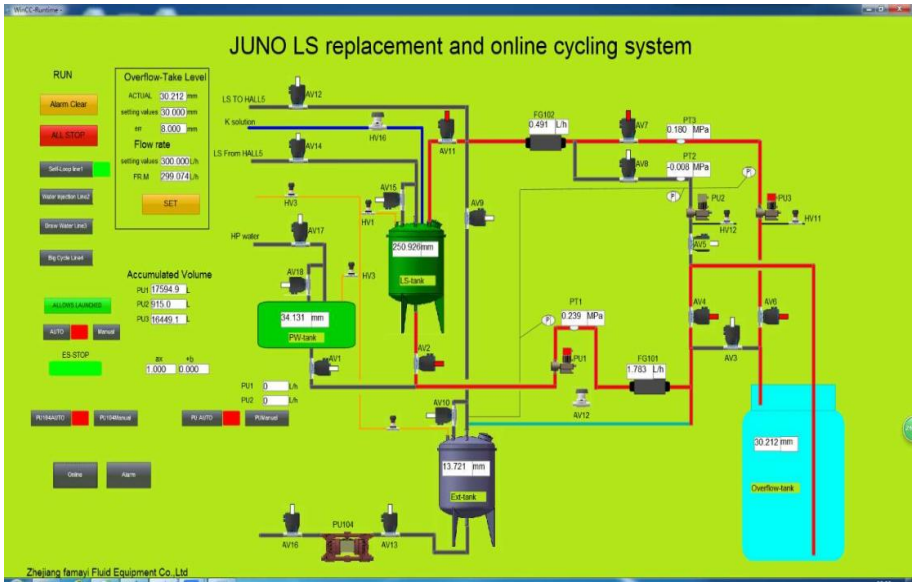
Pilot plant

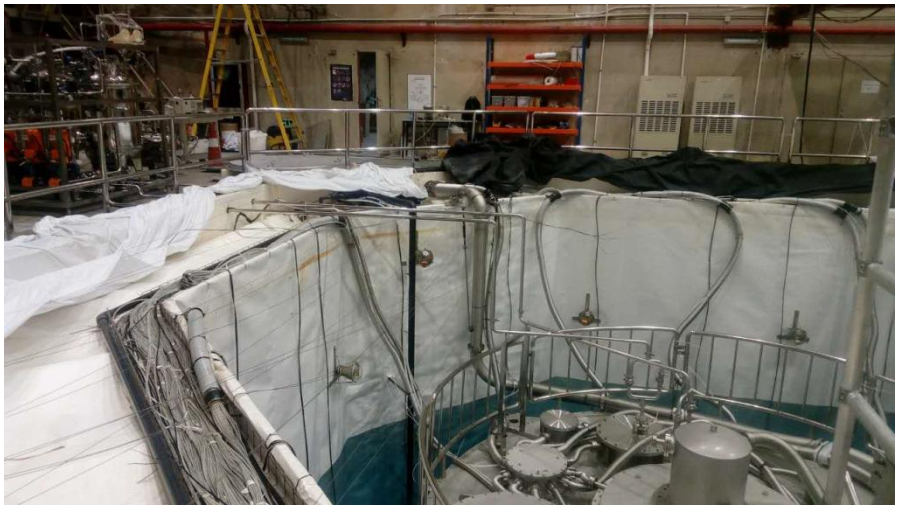
✓ Low background CarboACT active carbon used

# All systems have been installed in DYB LS hall



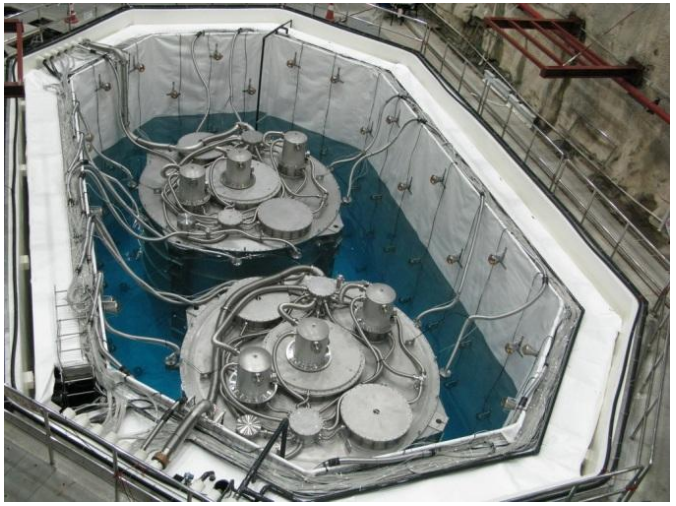

# The automatic control replacement system developed

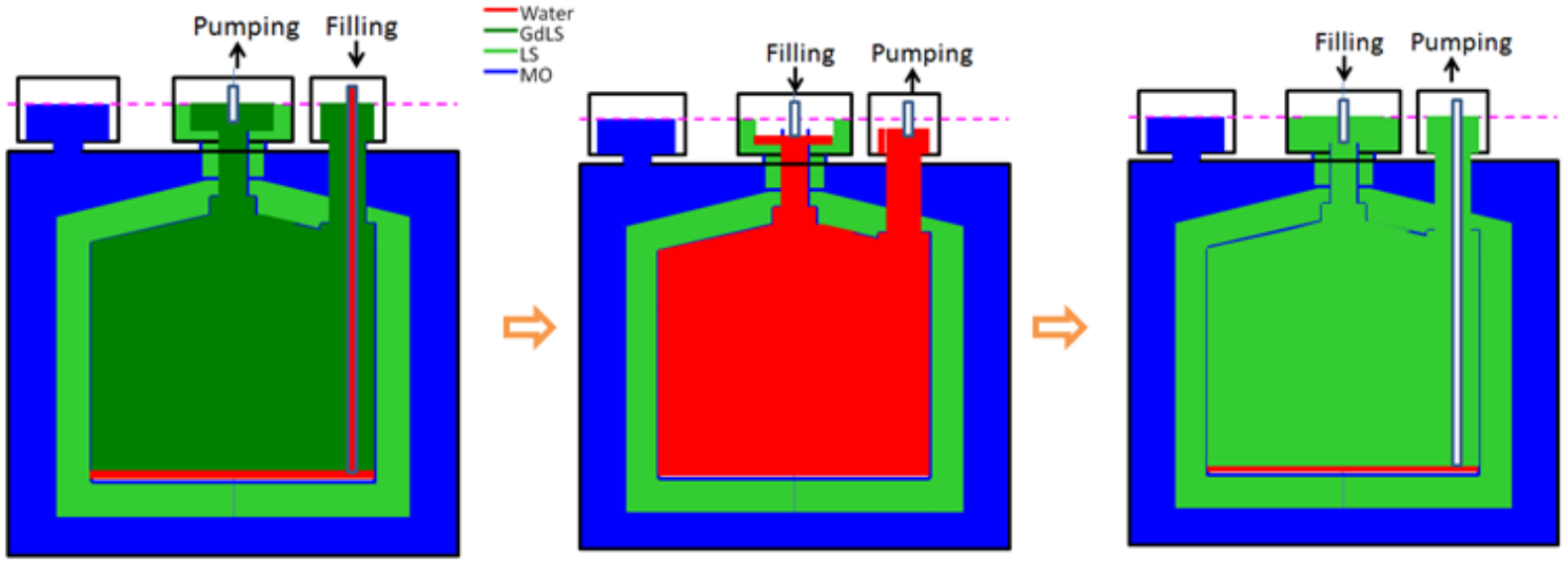


# The prototype test is going on

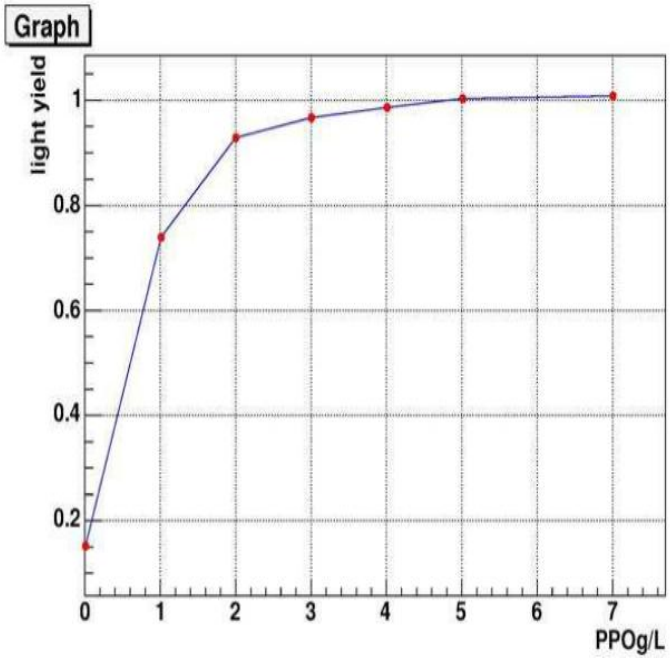
- The GdLS of one Dayabay AD has been replaced with purified LS ( 0.5g/L PPO )
- The radioactive background analysis is underway

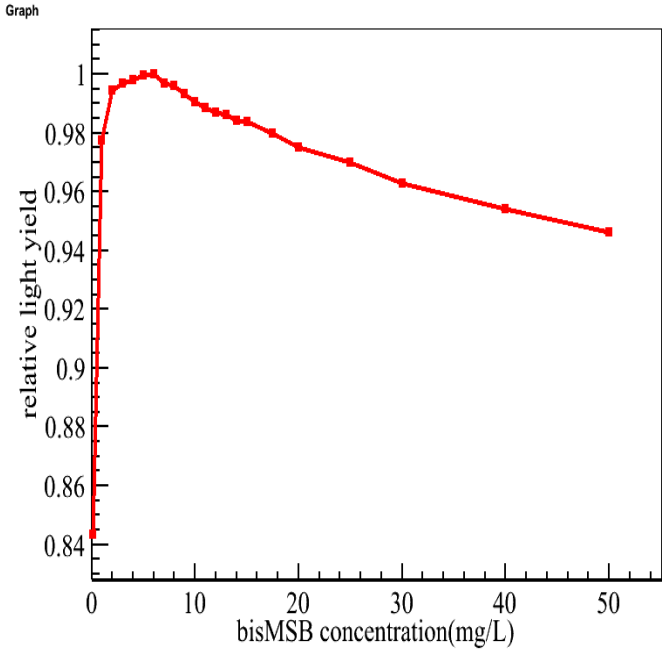




# LS recipe study

- More PPO and Bis-MSB is going to be added to study the light yield vs LS concentration
- To get the final JUNO LS recipe thereafter

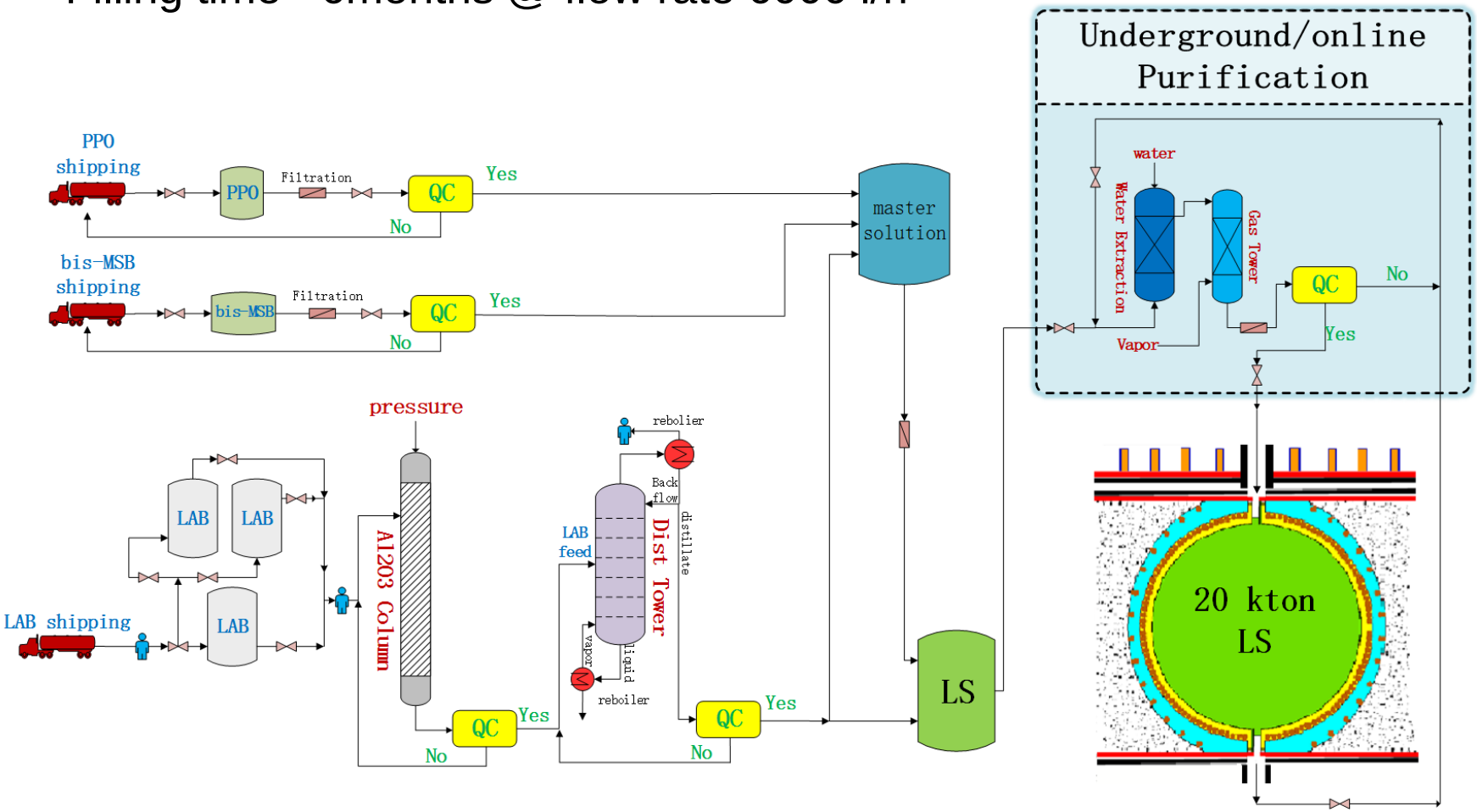


# LS Mass Production flow chart

**Preliminary design**

- 20kton LS will be purified by purification plants
- Filling time ~6months @ flow rate 6000 l/h



# Summary

- ✓ 20 ktons high light yield, high transparency and low background liquid scintillator needed for JUNO.
- ✓ Four LS purification systems include $Al_2O_3$ column, Distillation, Water extraction and Gas stripping studied.
- ✓ The prototype test with one DYB AD is underway

➢ JUNO Plan:

- 2017-2019,detector construction, assembly, installation
- 2020, LS filling
- 2020, start data taking

# Thanks!